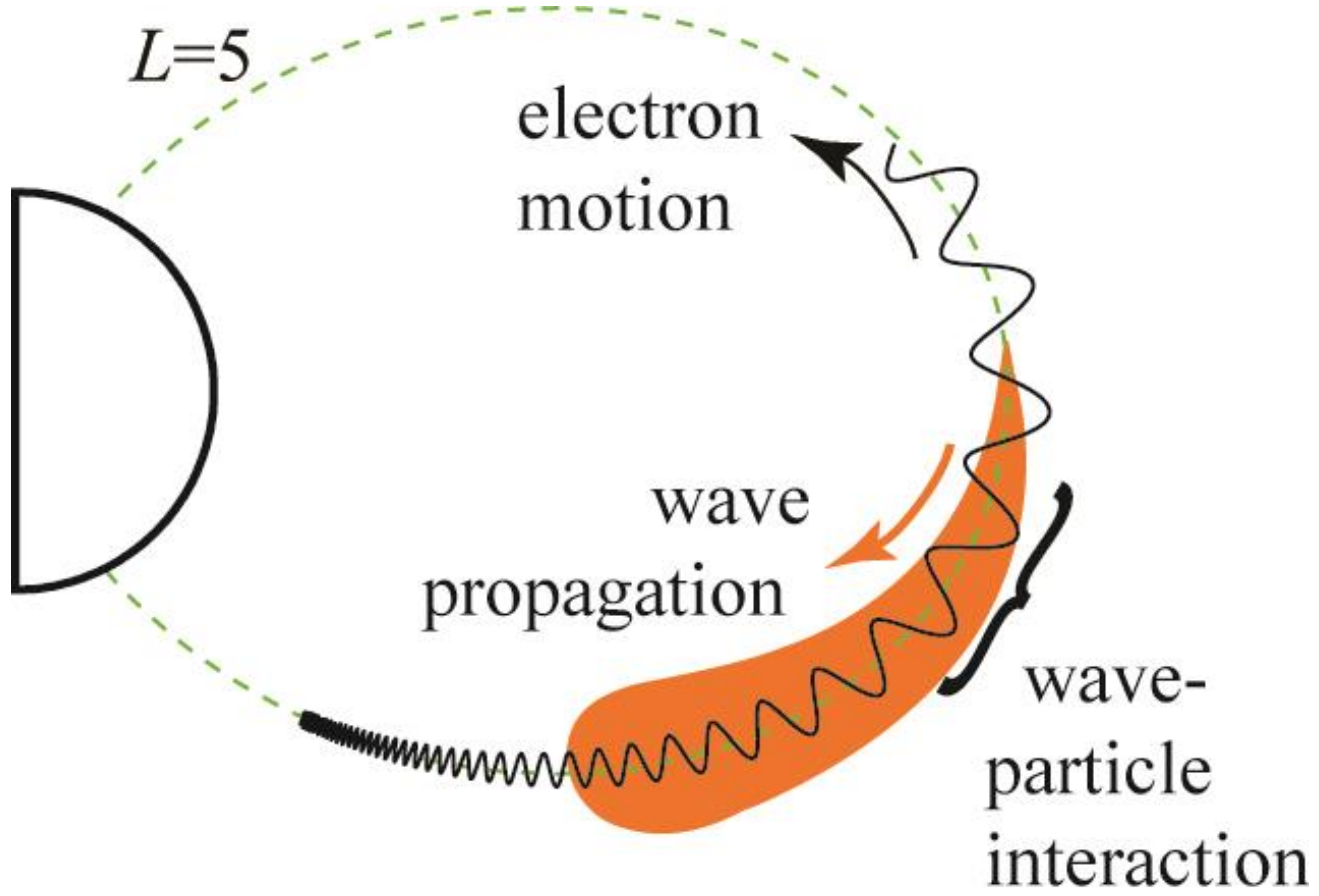
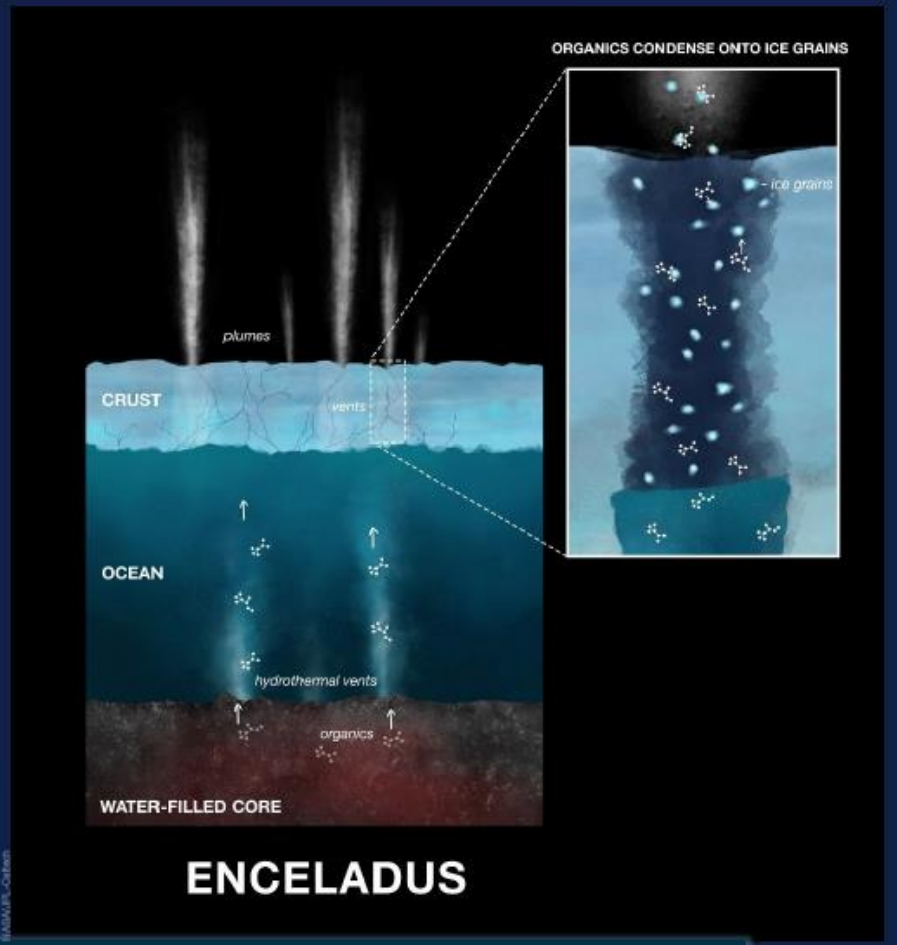
Space Physics Master's Course
Lecture 8
Storms and Van Allen Belts



Recent Scientific Highlights - Enceladus

New analysis of data collected as Cassini flew through a plume spraying from fissures on Enceladus' surface has identified new complex organic molecules in the sampled ice grains.
This demonstrates that complex chemical reactions are taking place within its subsurface ocean. Some could be part of chains that lead to even more complex, potentially biologically relevant molecules.



Update on L4 Mission to Enceladus

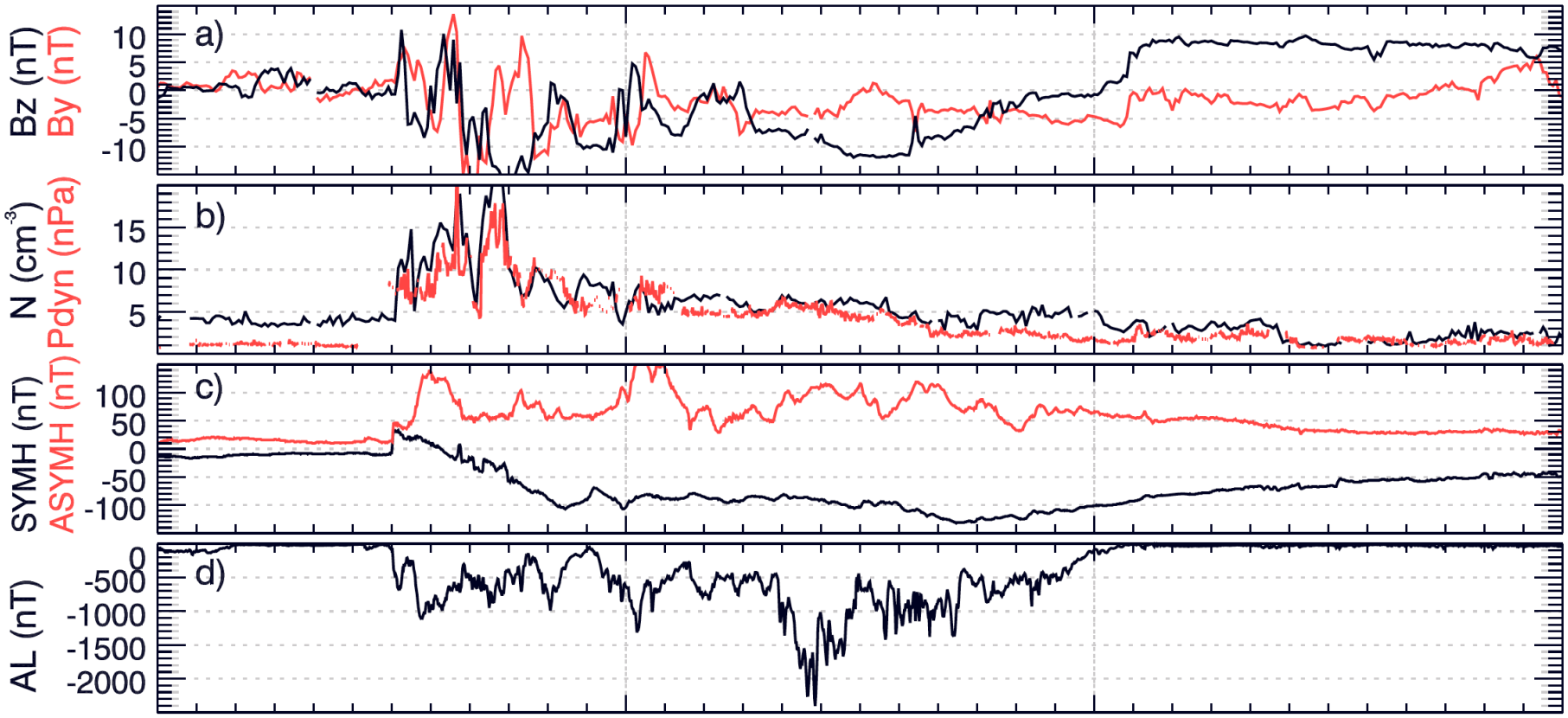
- Industry studies concluded in July demonstrated that the mission is technically feasible


LAUNCH WITH TWO ARIANE 6 ROCKETS
ASSEMBLE IN SPACE
JOURNEY TO SATURN
ORBIT SATURN
esa
TITAN
RHEA
DIONE
TETHYS
ENCELADUS
MIMAS
FLY BY SATURN'S ICY MOONS
SAMPLE PLUMES
ORBIT ENCELADUS
LAND ON THE SOUTH POLE OF ENCELADUS

List of F3 shortlisted for step-2

Title	Topic	Lead Proposer	Country
GRINTA: Exploring the dynamic universe through bursts, X-rays, and cosmic messengers	Astrophysics	Lorenzo Natalucci, INAF/Istituto di Astrofisica e Planetologia Spaziali	IT
GUEST: Gravitational Universe Exploration with Satellite Tracking	Fundamental Physics	Diego Blas, IFAE/ICREA	ES
Magnetotail Dynamics Explorer	Solar System	Andrew Fazakerley, Mullard Space Science Laboratory, University College London	UK
MESSIER Surveyor - Lifting the veil on the dark universe	Astrophysics	David Valls-Gabaud, Observatoire de Paris	FR
STEIN - Satellite Test of Einstein's gravitation theory	Fundamental Physics	Joel Bergé, ONERA - Paris Saclay University	FR
Proposals submitted as mini-F and moved to F			
Hannes - explore the physics of the small-scale dynamic aurora	Solar System	Mykola Ivchenko, KTH	SE
HYADES - Hydrogen And Deuterium Surveyor for Small Bodies in the Solar System	Solar System	Michal Drahus, Astronomical Observatory of the Jagiellonian University	PL
A Massive stars far-Ultraviolet Spectroscopic mission (MUSTI)	Astrophysics	Hugues Sana, KU Leuven, Institute of Astronomy	BE
ROARS: Research Observatory for Atmospheric Responses to Sun-magnetosphere interactions	Solar System	Ravindra Desai, University of Warwick	UK
SIRIUS - Stellar & ISM Research via In-orbit Ultraviolet Spectroscopy	Astrophysics	Martin Barstow, University of Leicester	UK
Wide-band Atmospheric Laboratory for Transiting Exoplanet Research (WALTzER)	Astrophysics	Luca Fossati, Space Research Institute, Austrian Academy of Sciences	AT

March 2013 storm, Van Allen Probes



Gkioulidou+, JGR 2014

Rikubetsu 1994 (Kamide+, JGR1998)

Substorms or convection?

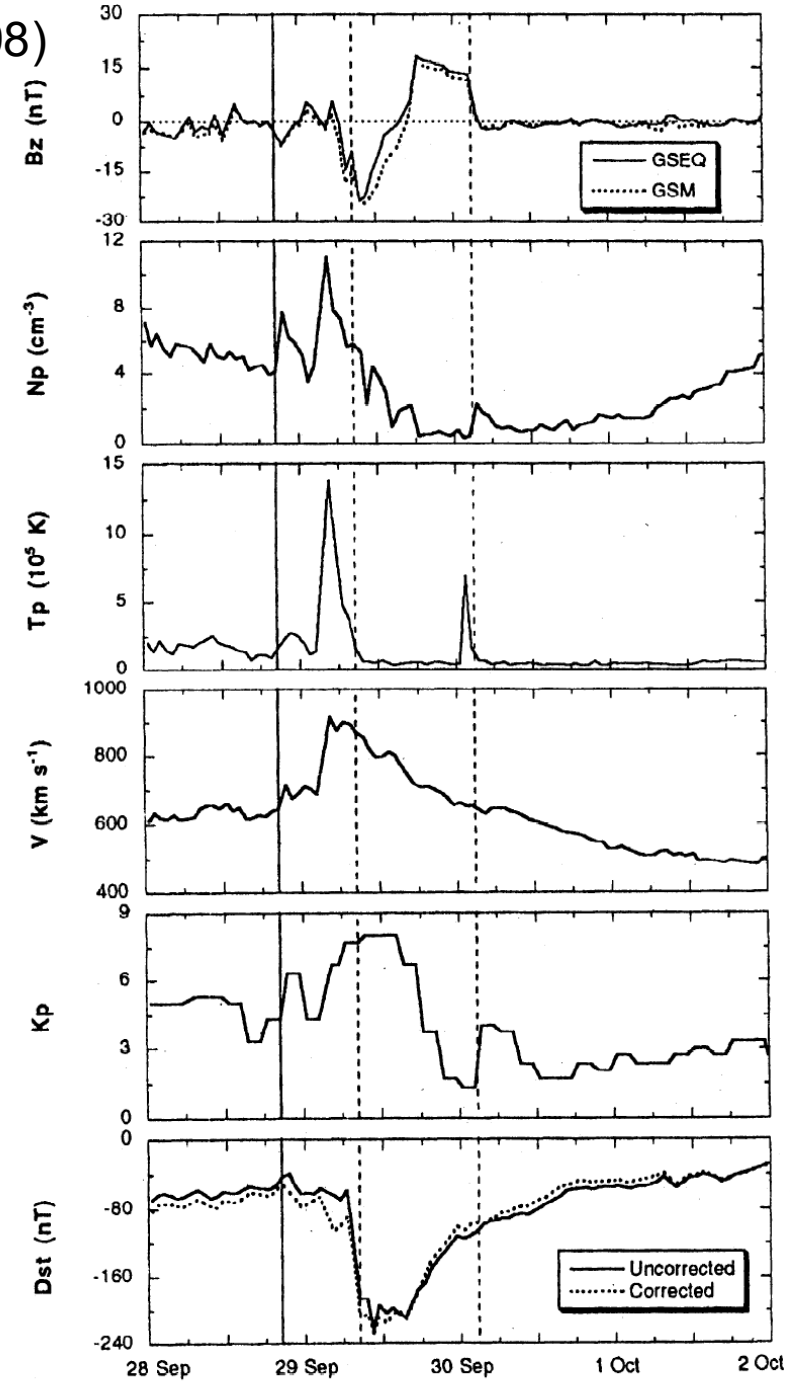


Figure 5. Interplanetary and geomagnetic data for a shock-ICME

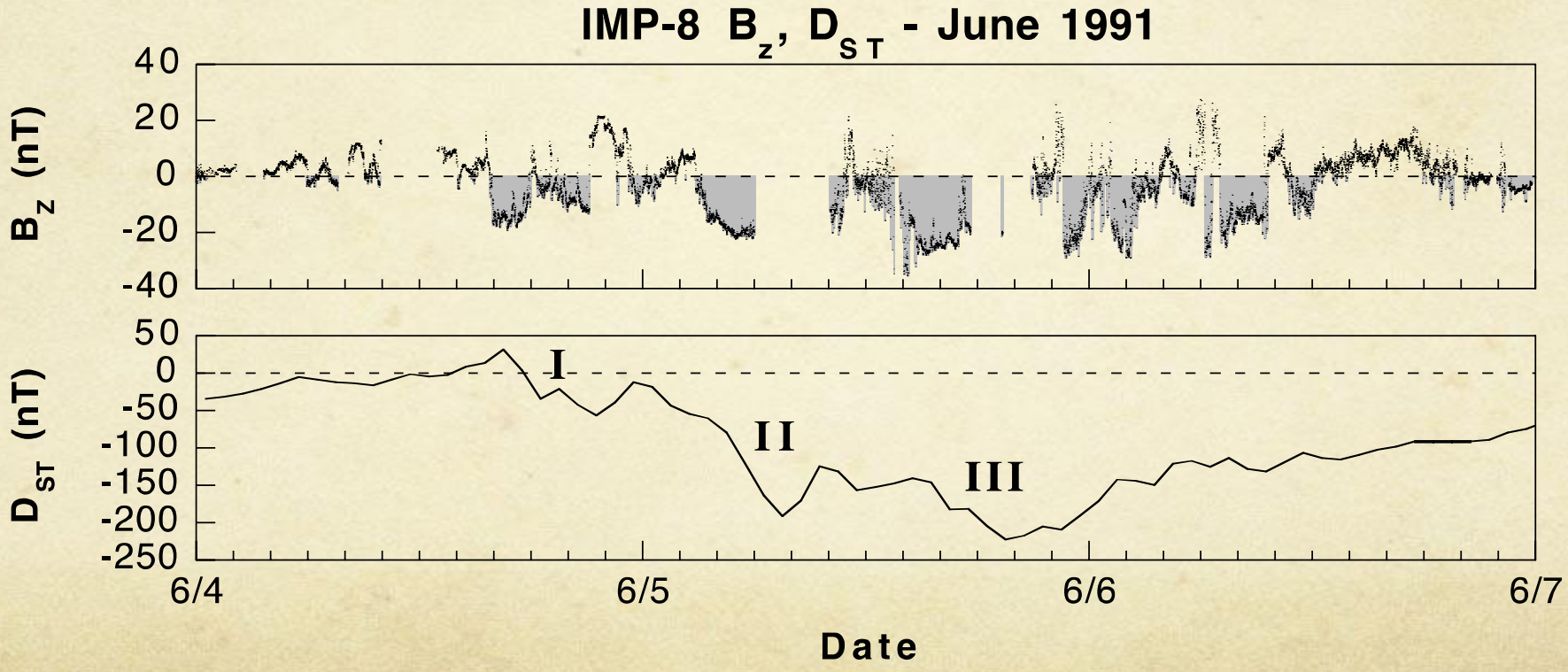
Substorms or convection?

Modeling efforts showed that
adiabatic acceleration associated with
earthward convection of ions under the
influence of the large-scale electric field
is sufficient to produce
the storm-time ring current

and therefore substorms are redundant.

Magnetic Storms

Require prolonged SW-magnetosphere coupling
(many hours of large IMF B_s / E_y)



Daglis et al., PSS 2007

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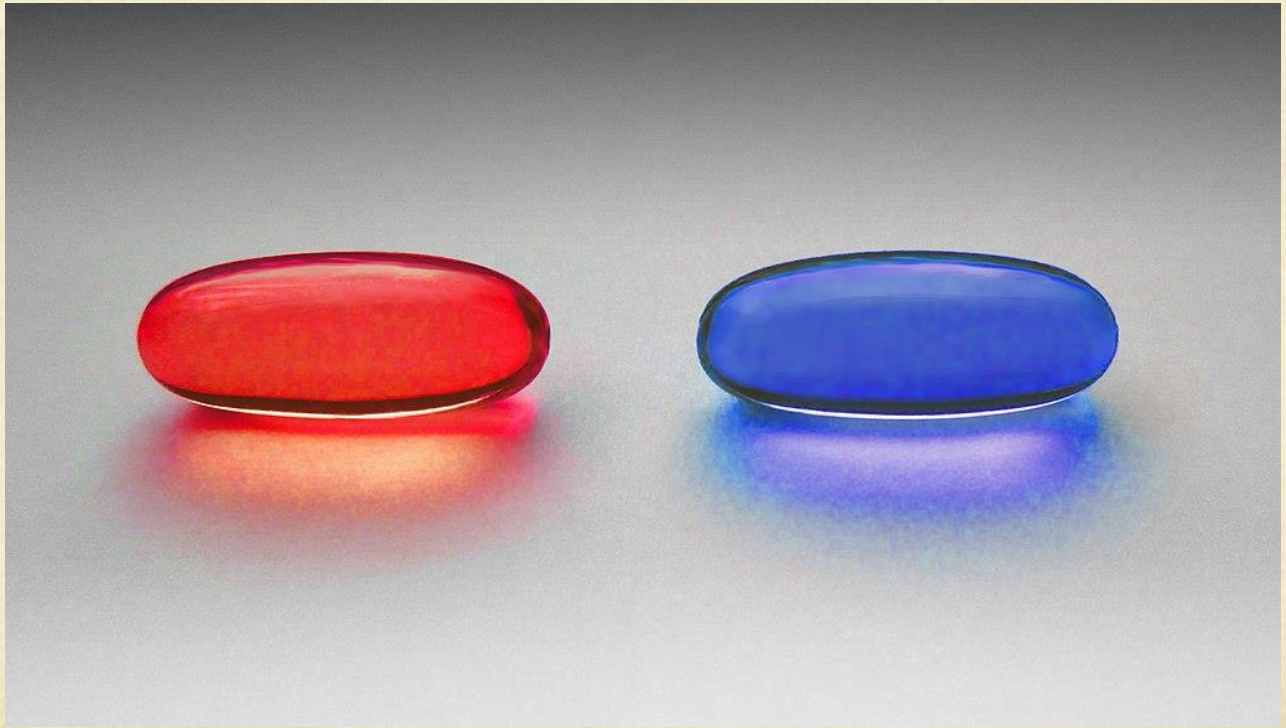
Substorms or convection?

Does reality confirm virtual reality?



The Matrix (1999)

Substorms or convection?

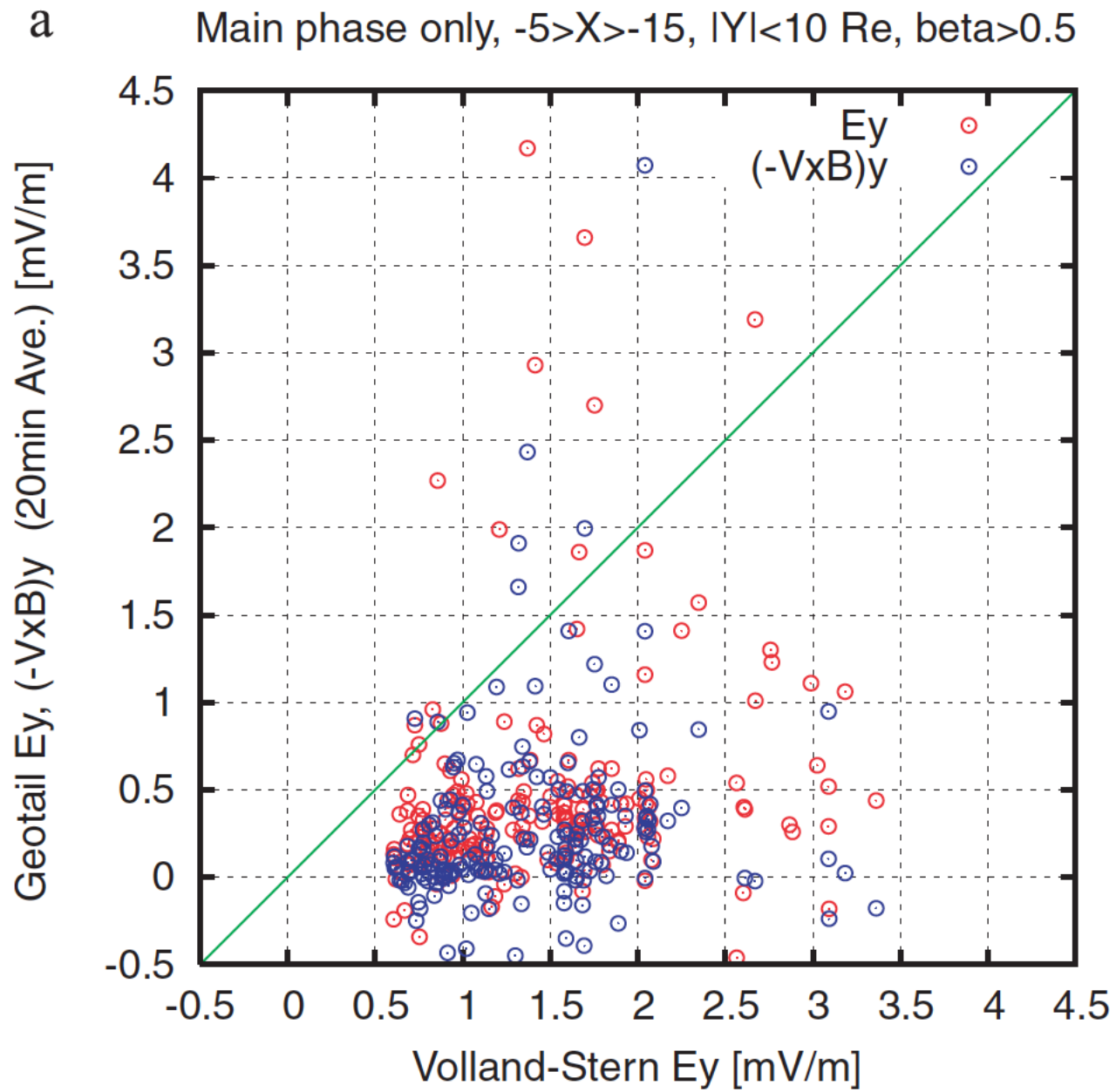
Basic assumption
of pro-convection, anti-substorm models:

tail / plasma sheet **E** follows closely IMF E_y
and, therefore, is enhanced during storms

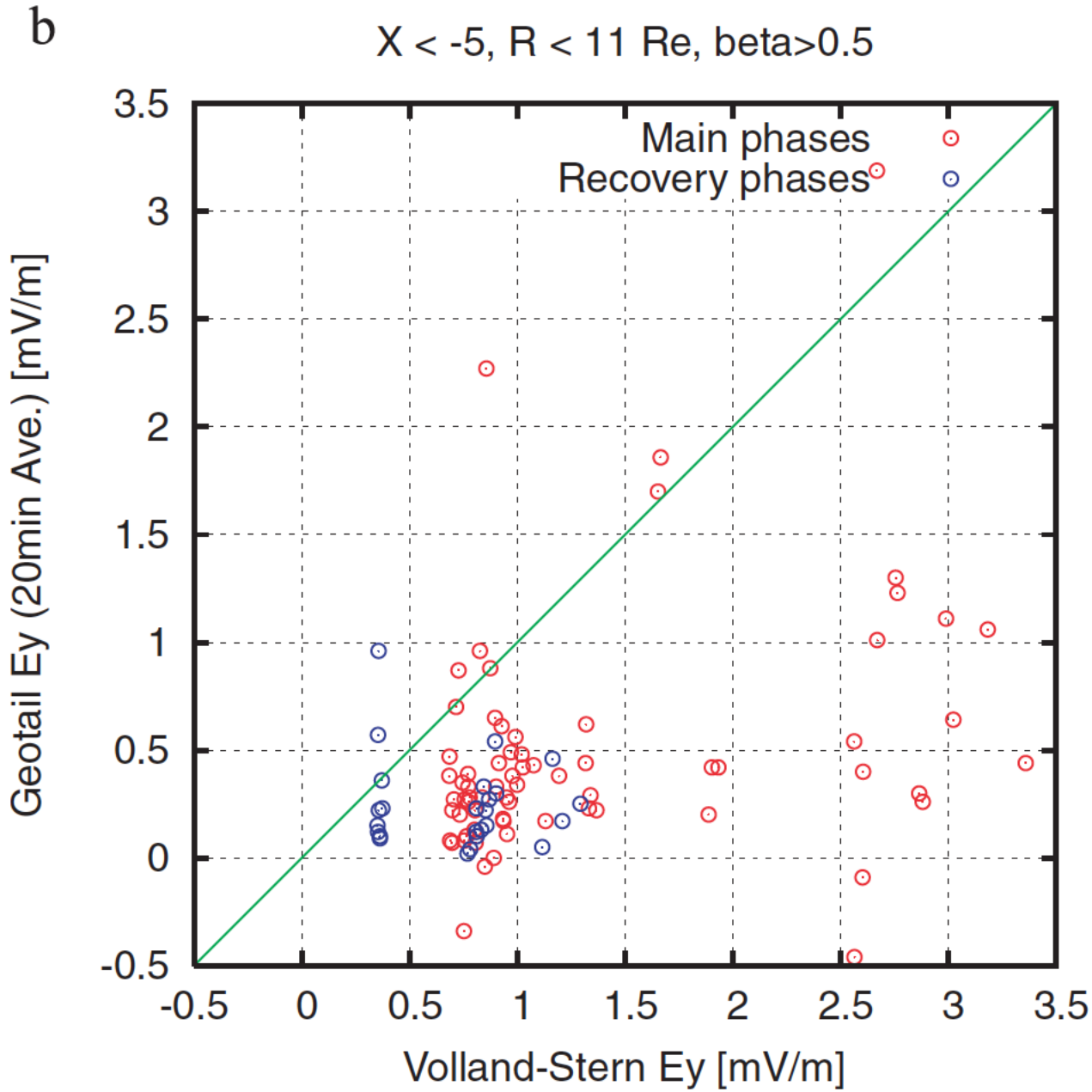
Substorms or convection?

Hori et al (JGR2005), 9 years Geotail data:

Large-scale electric field
in the near-Earth plasma sheet
is not enhanced
during storm main phase
and **does not** correlate well with IMF


a
Main phase only, -5>X>-15, |Y|<10 Re, beta>0.5
Ey
(-VxB)y
Geotail Ey, (-VxB)y (20min Ave.) [mV/m]
Volland-Stern Ey [mV/m]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

b


X < -5, R < 11 Re, beta>0.5
Main phases
Recovery phases
Geotail Ey (20min Ave.) [mV/m]
Volland-Stern Ey [mV/m]
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5

Substorms or convection?

Perfect results of models
are useless
if actual conditions
do not correspond
to the basic assumptions of the models

Substorms or ~~convection~~?

Perfect results of models
are **useless**
if actual conditions
do not correspond
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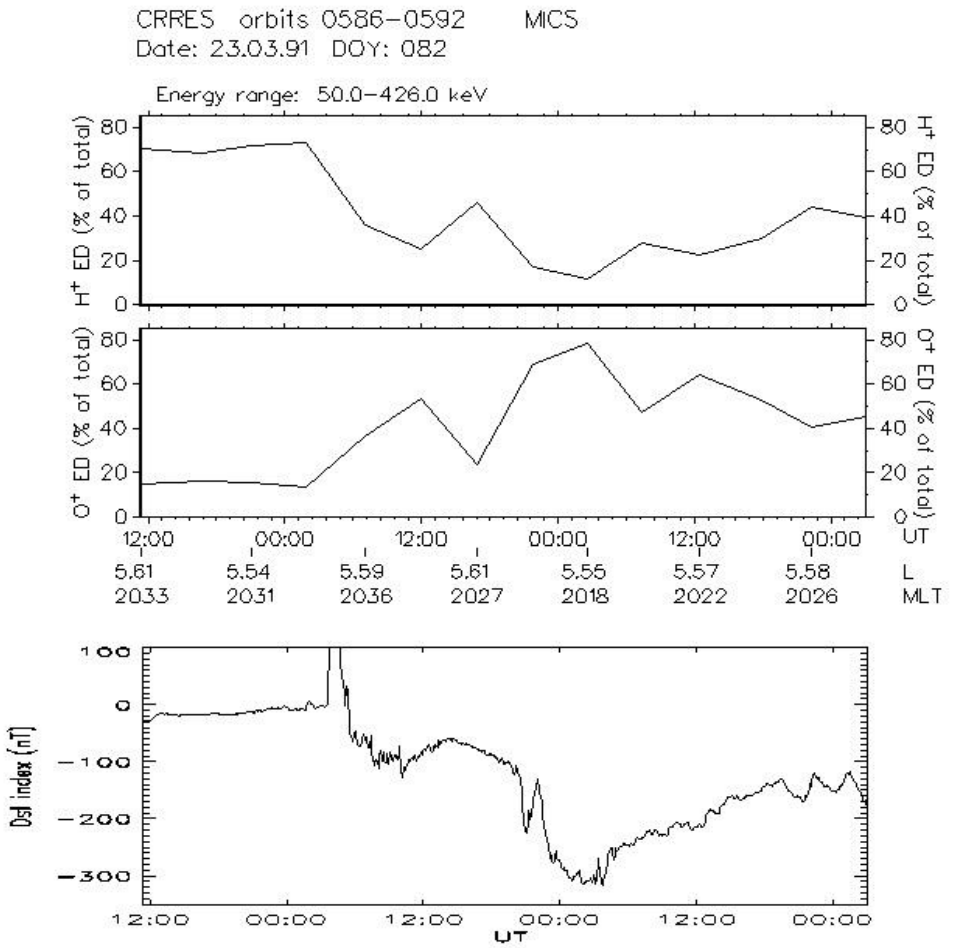
Ring current during intense storms



Daglis, GM 1997

Substorms and O^+ acceleration/dominance

Preferential acceleration

and subsequent dominance of O^+

advocate substorm role

(Delcourt / Daglis / Metallinou / Nose)

Substorm influence

More recently, Van Allen Probes observed frequent, **small-scale** proton injections deep into the inner magnetosphere in the region L~4-6.

Gkioulidou [2014] estimated that their overall direct effect can account for **~30%** of the energy gain in the ring current region

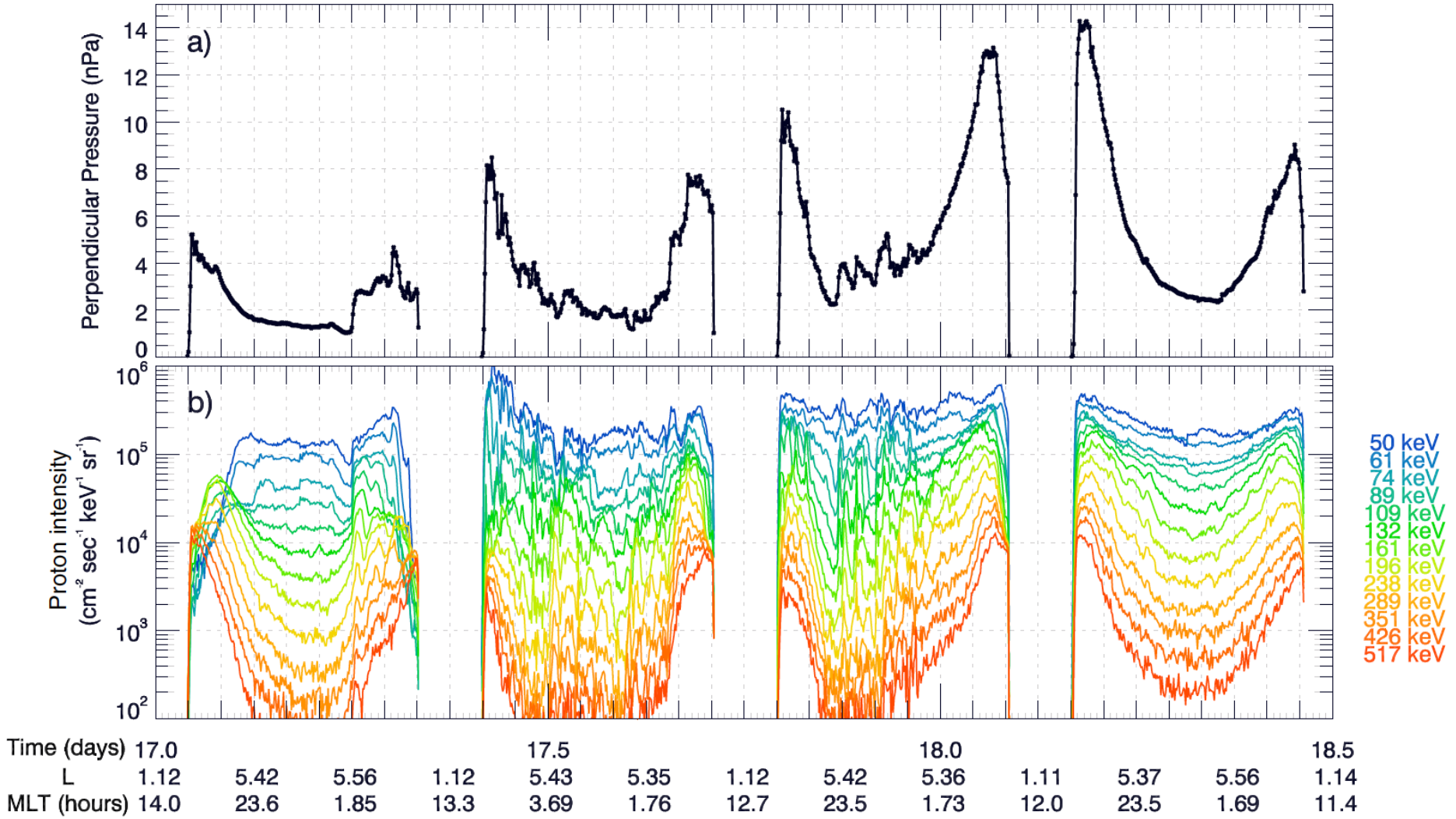


Figure 2. (a) Perpendicular pressure of 20 – 570 keV energy protons, and (b) intensities of 90 pitch angle protons for representative energy channels between 50 and 517 keV.

Gkioulidou+, JGR 2014

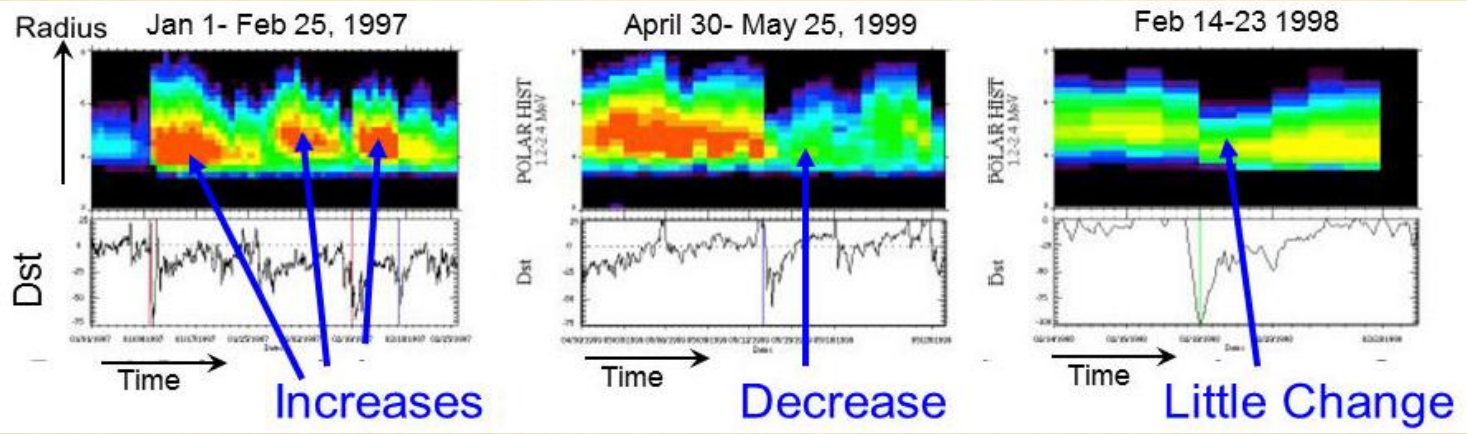
Storms and RBs

Magnetic storms
have a variable outcome
on relativistic electron fluxes

50% lead to **enhancement** of e^- fluxes

20% lead to **depletion** of e^- fluxes

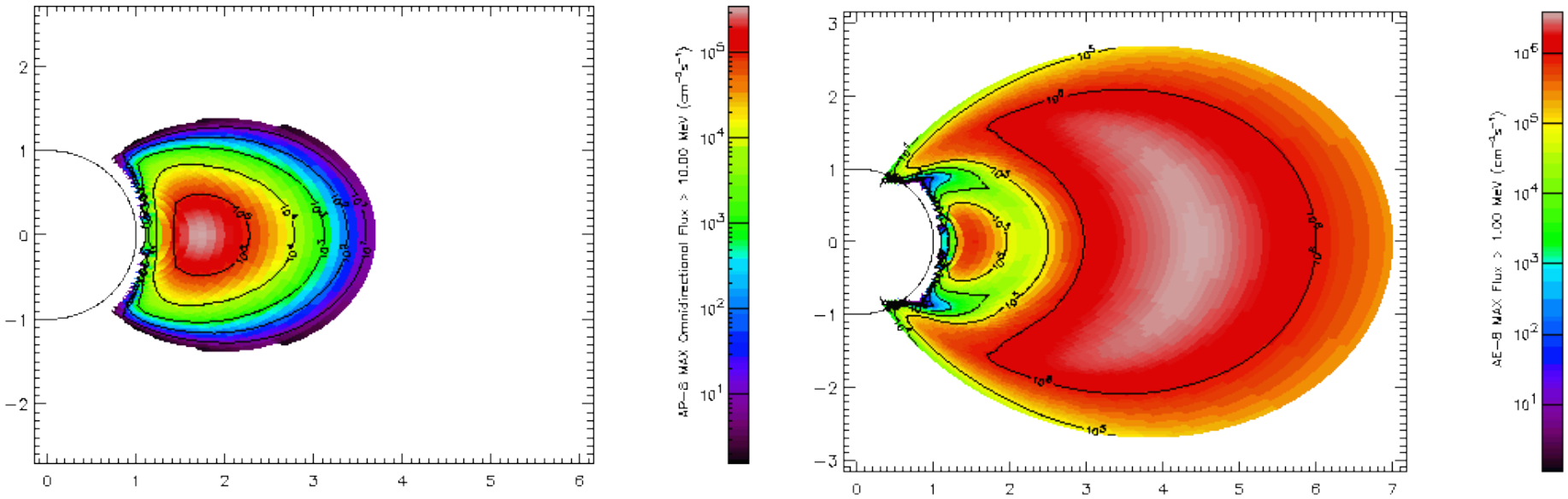
30% do not affect e^- fluxes



Reeves+, GRL2003


EUROPEAN SPACE
WEATHER WEEK

Radiation Belts: Inner, Outer



Main RB characteristics

Spatial extent

Inner belt:

$1.5 < L < 2.5$ (highly energetic H^+, energetic e^-)

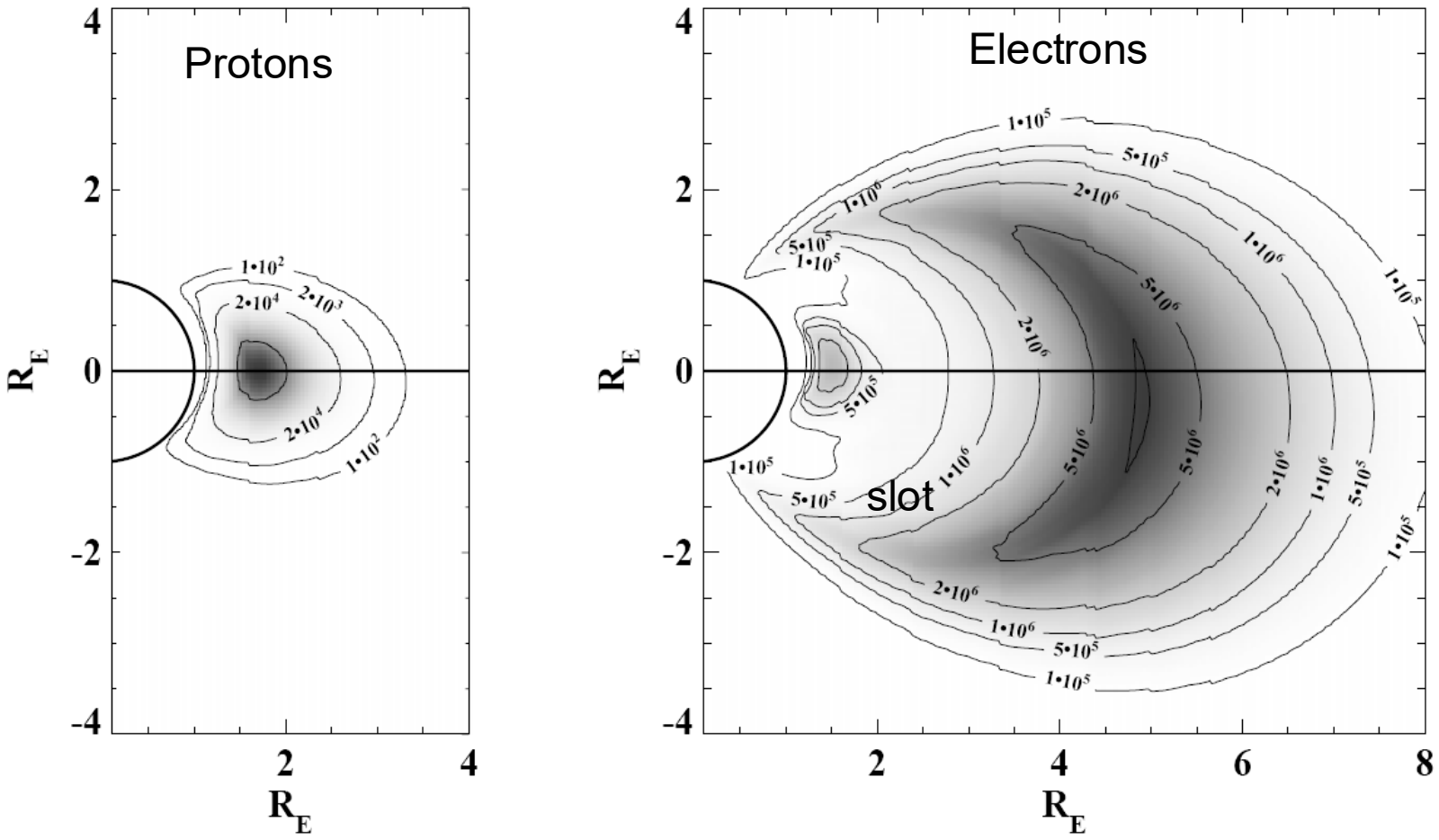
Slot electron zone:

$2 < L < 2.5$ (minimum of relativistic e^-)

Outer belt:

$2.5 < L < 7$ (energetic H^+, relativistic e^-)

Radiation Belts: Inner and Outer

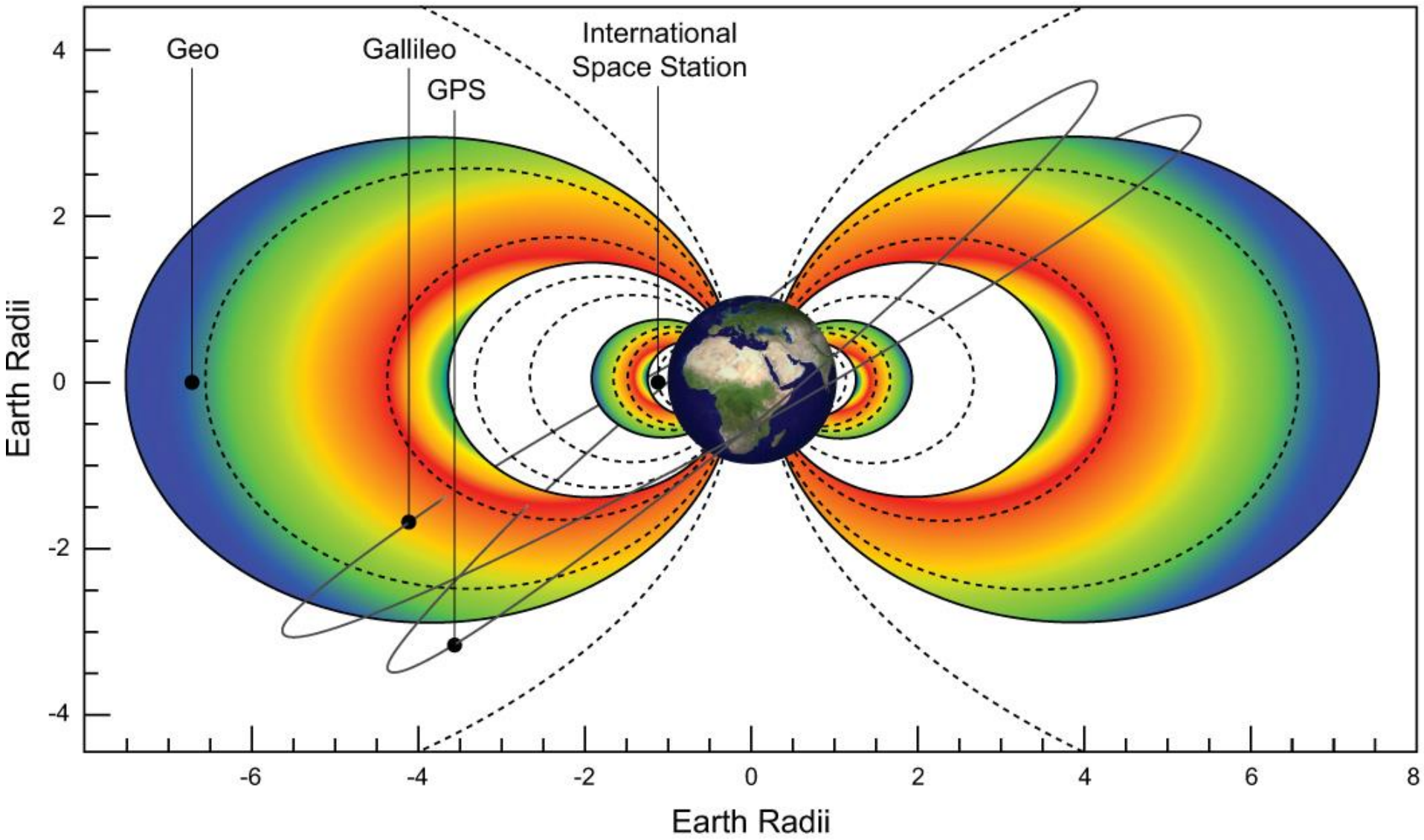


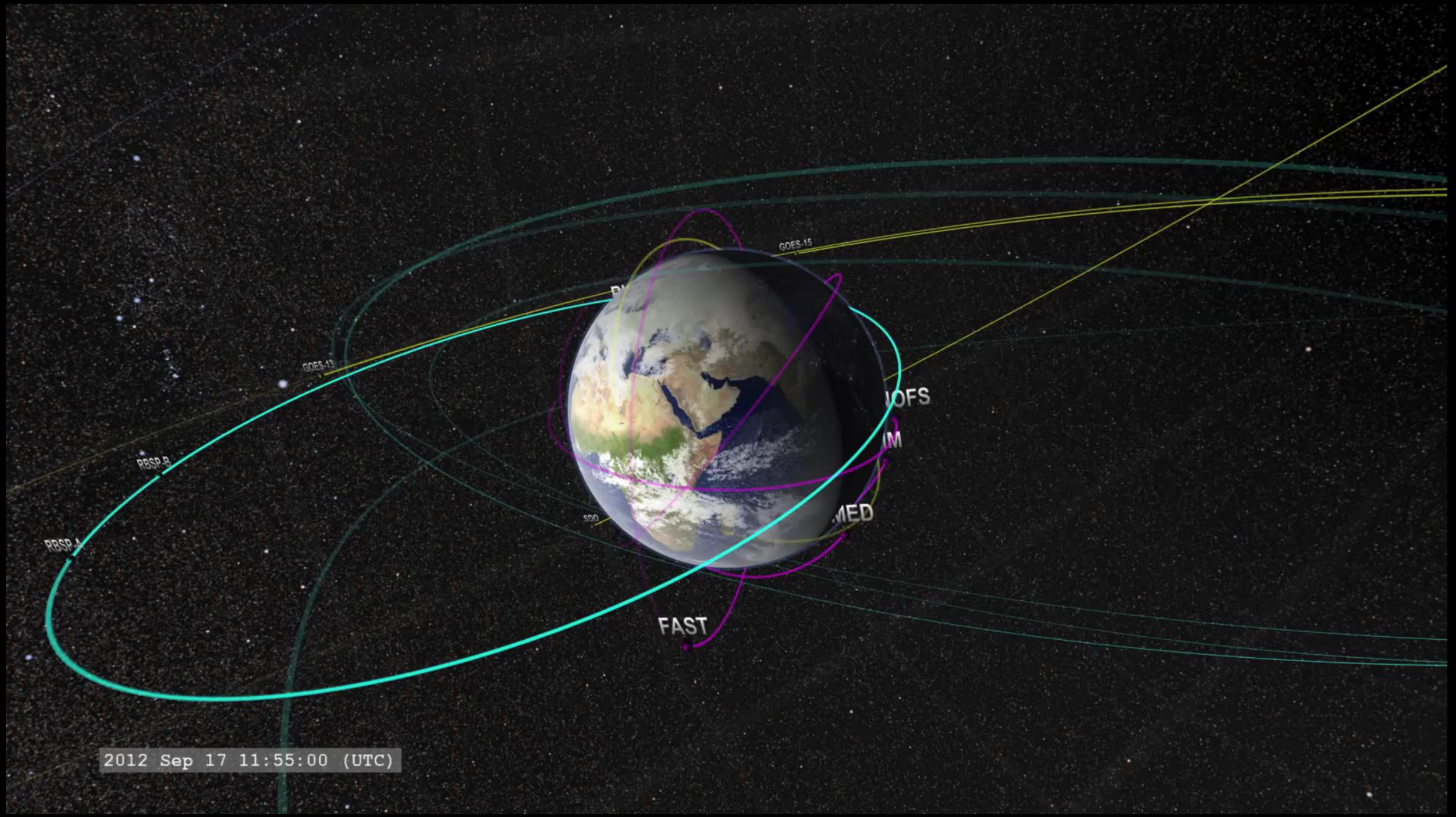
1.5 < *L* < 2.5 (highly energetic H^+, energetic e^-)

2 < *L* < 2.5 (minimum of relativistic e^-)

2.5 < *L* < 7 (energetic H^+, relativistic e^-)

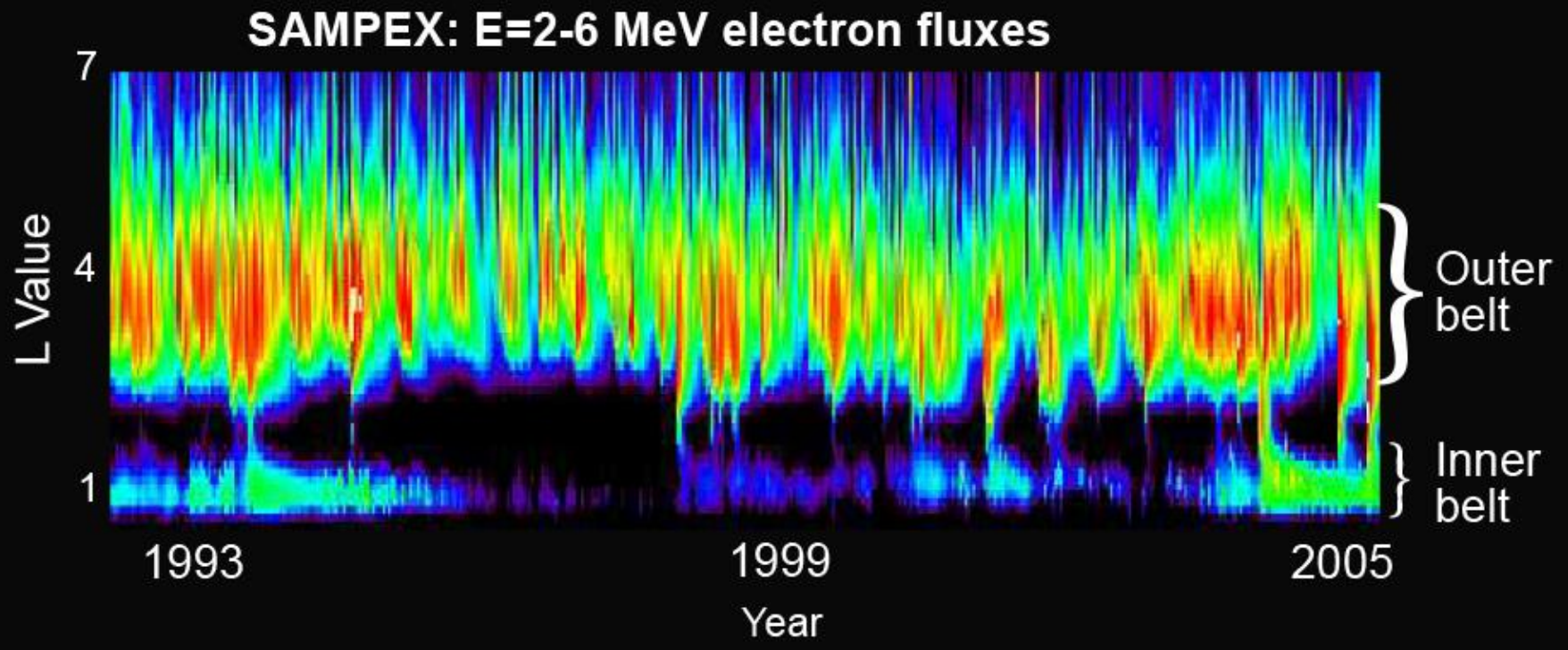
The Earth's Electron Radiation Belts




GOES-15
GOES-13
RBSP-B
RBSP-A
FAST
2012 Sep 17 11:55:00 (UTC)

SAMPEX Shows Traditional Two Belt Structure

Long term (~12 year) plot from SAMPEX shows the established two belt structure



Storms and RBs

RBSP confirmation:
Magnetic storms have a variable outcome

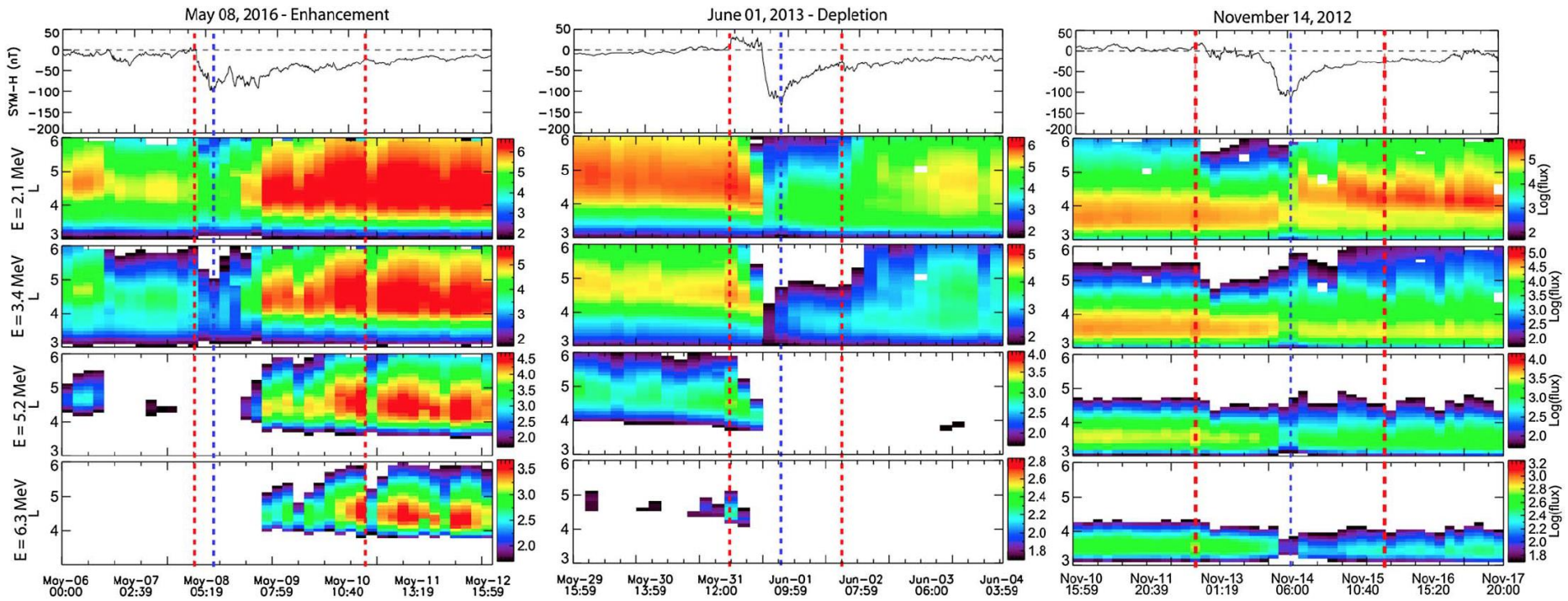
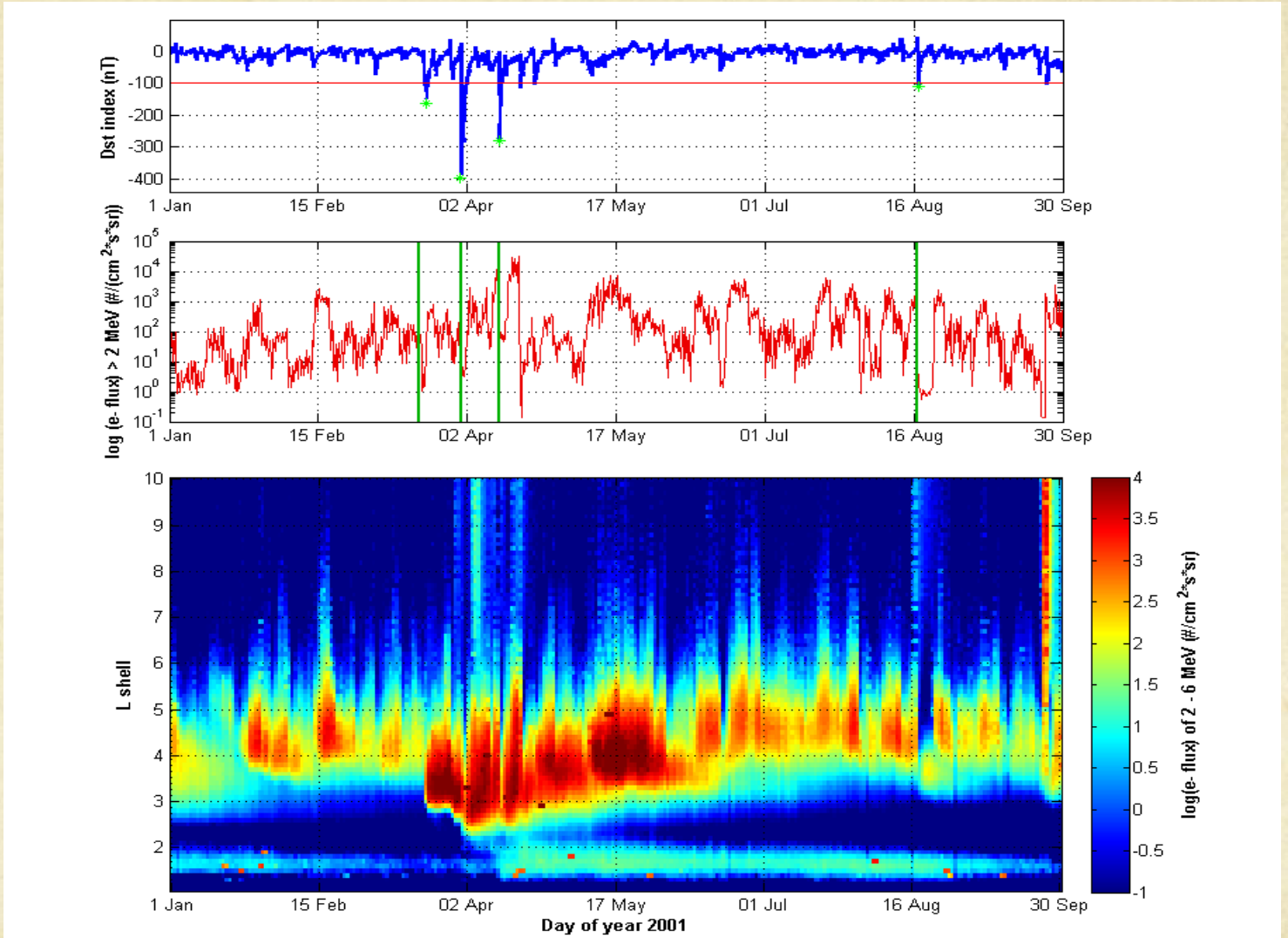


Figure 1. Three storm events showing, from top to bottom, *SYM-H* index and binned electron fluxes from REPT instrument for energy channels 2.1 MeV, 3.4 MeV, 5.2 MeV, and 6.3 MeV, respectively. Vertical lines show *SYM-H* minimum (blue) and duration of the storm (red). (left) An enhancement event resulting from a storm on 8 May 2016. (middle) A depletion associated with a storm on 1 June 2013. Figure 1 (left) shows a mixed event associated with a storm on 14 November 2012. Note that color scale is different for each panel. Flux values below background level are shown as white regions.

Moya+ JGR2017

March/April 2001 Storms



j > 5 orders of magnitude, e^- penetrate into slot and inner belt

Georgiou+ ANGEO2015